TAMPEREEN TEKNILLINEN YLIOPISTO
TAMPERE UNIVERSITY OF TECHNOLOGY

JUHA TEIKARI

ERECTION CONCEPT FOR BAG HOUSE FILTER

Master of Science Thesis

Examiner: Professor Risto Raiko

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ABSTRACT

TAMPERE UNIVERSITY OF TECHNOLOGY
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The purpose of this thesis is to develop an erection concept for bag house filters (BHF) for Valmet. Valmet used to deliver bag house filters in co-operation with the subcontractor, but during the last few years Valmet has provided bag house filters on its own. Although a few bag house filters have already been delivered, the erection concept needs improvement. The goal was to speed up bag house erection time and reduce work needed at erection area by finding factors that can be improved. Speeding up erection time is meant to be implemented by developing working methods and the structure of the bag house filter from the erection point of view without increasing costs.

In the beginning of the theoretical part, general matters concerning industrial emissions are explained and bag house filter and electrostatic precipitator principles are described. Also, basics of the project activities and construction planning are explained. Lean-philosophy is studied as appropriate. Finally in the theoretical part the methods and tools for schedule planning are more specifically examined.

In the practical part BHF principle, structure and erection concept are presented. In addition, in the practical part observations to speed up BHF erection are explained. Updated schedule, which was one of the goals of the thesis, can be found as an appendix. In the final part, the conclusion, the success of the thesis and its importance for the future are discussed.

TIIVISTELMÄ

TAMPEREEN TEKNILLINEN YLIOPISTO
Kemian ja biotekniikan laitos
TEIKARI, JUHA: Erection concept for Bag House Filter
Diplomityö
Marraskuu 2015
Pääaine: Voimalaitos- ja polttotekniikka
Tarkastaja: Professori Risto Raiko
Avainsanat: letkusuotimen asennus, aikataulutus, Lean, HSE, asennussuunnittelu

Tämän diplomityön tarkoituksena oli kehittää letkusuotimen asennuskonseptia Valmetilla. Valmet valmisti letkusuotimia aikaisemmin yhteistyössä alihankkijan kanssa, mutta viimeisen parin vuoden aikana Valmet on alkanut toimittaa letkusuotimia itsenäisesti. Vaikka muutamia letkusuotimia on jo toimitettu, on asennuskonseptissa vielä parannettavaa. Tavoitteena oli löytää asioita, joita kehittämällä letkusuotimen asennusaikataulua pystytään nopeuttamaan ja työmaalla tehtävää työmäärää vähentämään. Aikataulun nopeuttamista ei ole kuitenkaan tarkoitus tehdä lisäämällä kustannuksia vaan kehittämällä toimintatapoja ja letkusuotimen rakennetta asennuksen näkökulmasta.

Työn teoriaosuuden alussa taustoitetaan kirjallisuuden avulla yleisiä asioita teollisuuden päästöihin liittyen ja esitellään letku- ja sähkösuodattimen toimintaperiaate. Seuraavaksi esitellään projektitoiminnan ja asennussuunnittelun perusteita ja Lean-ajattelua soveltuvin osin. Teoriaosuuden viimeisessä osuudessa tarkastellaan projektien aikataulun suunnitteluun ja seurantaan liittyvien työkalujen ja toimintatapojen periaatteita.

Empiirisessä osuudessa käydään läpi letkusuotimen toimintaperiaate, rakenne ja asennustapa. Lisäksi empiirisessä osuudessa esitellään työn aikana havaitut asiat, joilla letkusuotimen asennusta voidaan nopeuttaa. Päivitetty asennusaikataulu, joka oli yksi työn tavoitteista, on liitteenä. Työn lopuksi päätelmissä pohditaan työn onnistumista ja sen merkitystä tulevaisuuden kannalta.

PREFACE

This Master's Thesis was made at Valmet Technologies construction planning department. During the thesis I attained a change to develop important skills regarding my current position.

Especially, I want to thank Suvi Reinikka for giving me the opportunity to do this assignment. Moreover, I would like to extend my thanks to mechanical engineering wizards Hannu Similä, Jere Fabritius and Antti Kemppainen, whose professional advices and support in practical matters gave me deeper understanding about the subject. I want to also give my thanks to site supervisors Manuel de Jesus and Pasi Myllymäki who were willing to sit down with me and talk about their BHF erection experiences. I'm also grateful to Ella Nousu and Ulla Oksanen for proofreading this thesis.

Special thanks belong to Professor Risto Raiko for understanding and support shown during my studies at the Tampere University of Technology.

Tampere, 17.3.2016

Juha Teikari

ABBREVIATIONS AND NOTATIONS

BHF	Bag house filter, an air pollution control device that removes particulates out of air or gas released from commercial processes or combustion.
Bidding process	Competitive bid process is mostly used in the procurement of goods and services. The process entails submitting a sealed envelope detailing the price and terms of an offer. The recipient of the offer then selects the competitive bidder that has delivered the lowest price or best terms.
DFMA	DFMA is the combination of two methodologies; Design for Manufacture (DFM), which means the design for ease of manufacture of the parts that will form a product, and Design for Assembly (DFA), which means the design of the product for ease of assembly.
ESP	Electrostatic precipitator, a filtration device that removes fine particles, like dust and smoke, from a flowing gas using the force of an induced electrostatic charge minimally impeding the flow of gases through the unit.
Erection area	Erection area is a part of the construction site. The erection area is the “core” of the construction site where all the erections and installations take place.
I.D. fan	I.D. is "Induced Draft". In an induced draft system, the fan is at the exit end of the path of flow, and the system is under negative pressure. The pressure in the flow area is below atmospheric because the air is being drawn through the fan.
Lean	The core idea of Lean-philosophy is to maximize customer value while minimizing all the activities that do not add any value.
Life cycle	The total phases through which an item passes from the time it is initially developed until the time it is either consumed in use or disposed of as being excess to all known material requirements
Odorous gas	Strong scent can be described as odorous. Usually if something is odorous it means that it smells unpleasant.

Pre-fabrication area	An area that is used for example for ducts, piping, bag house filters and other components pre-fabrication. Pre-fabrication area might be located a bit further from an actual construction site.
WBS	Work breakdown structure is a key project deliverable that organizes the team's work into manageable sections. WBS can be defined as a deliverable oriented hierarchical decomposition of the work to be executed by the project team.

TABLE OF CONTENTS

1. Introduction

In this chapter the background for the thesis is explained. In addition, the purpose and the structure of the thesis as well research methodology are presented.

1.1. Background

Valmet has over 200 years of industrial history starting as a small shipyard in 1750s. Today Valmet is a global developer and supplier of technologies, automation and services especially for industries that use bio-based raw materials, primarily the pulp, paper and energy industries as well as selected process industries.

Valmet practices typical international project business, and the duration of the largest projects can be several years starting from the bidding process until the customer has taken over the paper mill or power plant. Valmet business consists of four different business lines: *Services business line* provides customers mill improvements, roll and workshop, spare parts, fabrics, and life-cycle services; *Pulp and Energy business line* provides technologies and solutions for pulp and energy production as well as for biomass conversion. The pulp projects range from process equipment deliveries to complete pulp mills. *Paper business line* deliveries complete board, tissue and paper production lines and machine rebuilds; *Automation business line* delivers automation solutions ranging from single measurements to mill wide process automation systems for pulp, paper and other process industries. (Valmet public internet site)

Valmet Environmental Systems (ES) department is specialized in flue and odorous gas cleaning and it is part of the Valmet Pulp and Energy business line. ES projects are relatively short-term compared to the extensive mill and power plant projects because the scope of supplies and equipment delivered are usually a lot smaller.

Typical duration for erections and installations made at the construction site in ES delivery projects is approximately 2-6 months. Although the erections and installations are made comparatively fast at the site, the goal is to reduce that time period as short as possible. The purpose is to keep site operation costs as low as possible. The customer pays for the facilities, and it is up to the contractor how much money they spend on operations to deliver and erect those ordered facilities. Well planned and scheduled installations and material flow are essential for fluent site operations in order to keep costs in budget.

In ES projects a significant portion of the project direct costs are committed at site. Poor planning may cause significant unexpected costs and even put the whole project in risk if major delays are resulted from planning failures.

1.2. Purpose of the thesis

Valmet produced Bag House Filters (BHF) earlier together with the subcontractor but co-operation ceased a few years ago and Valmet started to deliver BHF on its own. The purpose of this thesis is to develop the erection concept for BHF and especially to study what is the shortest erection time for this new BHF, officially called GASCON® BHF, with reasonable costs. A few new BHF have already been erected but the erection concept might need some improvement.

1.3. Research methodology

The theoretical part of this thesis consists of the basics of the different tools for project management and scheduling. Furthermore, the basic idea of the Lean philosophy will be studied and some of its tools which can be utilized in construction planning.

The practical part of the thesis is based on the experiences and ideas gathered from Nokia and other previous construction sites. In practice, as a result of the thesis, an improved erection concept for BHF should be formed.

1.4. Structure of the thesis

The thesis consists of eight chapters, of which the first is an introduction to the subject and research. In the second chapter, regulations, emissions and cleaning systems related to flue gases are presented. Third and fourth chapters consist of theoretical background for construction planning and Valmet HSE. In the fifth chapter Lean philosophy and some of its tools are presented. Scheduling and its components are discussed in more detail in the sixth chapter. In the seventh and eight chapter the practical part is explained and conclusion from the results are made, and recommendations and suggestions for further actions are presented.

2. Flue gas cleaning

In this chapter fundamentals of the emissions from power plants and cleaning systems are presented. It is also important to understand that the regulations for the environmental protection are set by EU and the limits for the emissions from power plants will tighten in the near future. Similar emission control actions have been taken all over the world. For example, in China new emission standard GB 13223-2011 of air pollutants for thermal power plants was set in January 2012. Standard GB 13223-2011 is even tighter than European 2010/75/EU, for example NOx emission for new coal fired power plants is set to 100 mg/m^3 compared to European 200 mg/m^3. (Ministry of Environmental Protection)

2.1. EU regulations

The purpose of Directive 2010/75/EU is to prevent, reduce and as far as possible eliminate pollution arising from industrial activities practicing in principle where polluter is responsible for the costs and the principle of pollution prevention. It was necessary to create a general framework in EU for the control of main industrial activities, giving priority to intervention at source. Also reasonable management of natural resources, economic situation, needs and local characteristics of the place where the industrial activity occurs need to be taken into consideration.

Different approaches to control emissions into air, water or soil separately may encourage shifting from one polluting substance to another. It is more important to protect nature as a whole. Therefore it is appropriate to provide an integrated approach to prevention and control of emissions into air, water and soil, to waste prevention, to energy efficiency and to accident prevention. Such an approach will also make more honest and fair market in the EU for industrial installations because environmental performance requirements are the same for everyone.

According to Directive 2010/75/EU given by European Parliament 24. November 2010 new limitations of emission of certain pollutants for large combustion plants were set. This directive replaces number of previous directives including 2001/80/EU. Its purpose is to limit the amount of sulphur dioxide, nitrogen oxides and dust emitted from large combustion plants. It also encourages combined production of heat and electricity.

In this case large combustion plants are considered plants with rated thermal input equal to or greater than 50 MW, irrespective of the type of fuel used (solid, liquid or gaseous). Under the terms of the directive, combustion plant built after 1. July 1987 must comply with specific emissions limits. From 1. January 2008 on, plant built earlier than that could either choose to comply with the emissions limits or shut off. Plants which decided to shut off have been limited to a maximum of 20,000 hours of further operation and must close completely by the end of 2015. (Official Journal of the European Union 2010)

Table 1. (Official Journal of the European Union 2010)

Emission limit values (mg/Nm^3) for NO_x for combustion plants using solid or liquid fuels with the exception of gas turbines and gas engines

Total rated thermal input (MW)	Coal and lignite and other solid fuels	Biomass and peat	Liquid fuels
50-100	300 450 in case of pulverised lignite combustion	300	450
100-300	200	250	200 (1)
> 300	200	200	150 (1)

Note:

(1) The emission limit value is 450 mg/Nm^3 for the firing of distillation and conversion residues from the refining of crude-oil for own consumption in combustion plants with a total rated thermal input not exceeding 500 MW which were granted a permit before 27 November 2002 or the operators of which had submitted a complete application for a permit before that date, provided that the plant was put into operation no later than 27 November 2003.

Table 2. (Official Journal of the European Union 2010)

Emission limit values (mg/Nm^3) for dust for combustion plants using solid or liquid fuels with the exception of gas turbines and gas engines

Total rated thermal input (MW)	Coal and lignite and other solid fuels	Biomass and peat	Liquid fuels (1)
50-100	30	30	30
100-300	25	20	25
> 300	20	20	20

Note:

(1) The emission limit value is 50 mg/Nm^3 for the firing of distillation and conversion residues from the refining of crude oil for own consumption in combustion plants which were granted a permit before 27 November 2002 or the operators of which had submitted a complete application for a permit before that date, provided that the plant was put into operation no later than 27 November 2003.

2.2. Emissions from power plants

Most of the energy in the world is produced by combustion process. It is obvious that combustion will remain as a major production form in the future despite of the development of other energy production methods. One of the most important goals which has been set for the combustion process, in addition to high efficiency and reliability, is to minimize emissions at as low cost as possible. Most significant emissions from fossil fuel combustion are nonflammable gases, for example CO, nitrogen oxides (NO_x, N_2O) and sulphur dioxide (SO_x). Many emissions can be essentially reduced in the combustion process by using state-of-the- art burning technology or adding chemicals into the furnace. It is easier and cheaper to reduce emissions early in the combustion process than at later stages of the process. It is typical that methods used early in the combustion process are not sufficient to reduce emission to under continually tightening limits. However, at least it makes it easier and cheaper to clean up flue gases using scrubbers, filters, electrostatic precipitators and SCR etc., later in the process because flue gases are already cleaner. (Raiko *et al.* 2002, p.60)

Air pollution problems are the result of emissions from various types of sources. Most significant is pollution from the use of fossil fuels. These so-called primary pollutants can arise in various ways:

- As a product of the combustion, where it usually is in formation of carbon dioxide. Combustion or incomplete combustion may also lead to the formation of new compounds. Typical examples are carbon monoxide, nitrogen oxides and hydrocarbons.
- As impurities or additives to the fuel. Typical examples are sulphur in oil and lead in petrol.

Sulphur dioxide, SO_2, in air is mainly the result of sulphur in fossil fuels. In general, the heavier the fuel, the higher the content of the sulphur. Uncleaned coal may contain up to few percent sulphur, oil 0.5 %, gasoline 0.05% and natural gas practically none. Anyhow, in the industrialized world, the problem is solved to some extent by using purified fuels and desulphurising systems in the exhaust. (Fenger & Tjell 2009, p.54)

Nitrogen oxides, NO and NO_2, are formed from the free nitrogen (N_2) in combustion air at high temperatures in combustion processes or they can originate from nitrogen content in the fuel. Nonetheless, emissions are heavily dependent on combustion conditions and the nitrogen content of the fuel is not significant. In general, the main part (90-95%) is emitted in the form of NO (nitrogen monoxide) that is subsequently oxidized by ozone in the atmosphere to NO_2 (nitrogen dioxide). In emission summaries usually the sum of NO and NO_2 is indicated as NO_x. NO_x emissions can be handled by changing combustion conditions or by using catalytic converters. (Fenger & Tjell 2009, p.55)

Carbon dioxide, CO_2, is the end product in combustion of all fossil fuels. CO_2 itself is harmless in present concentrations and is even an essential substance in photosynthesis. However, during recent decades concentration has raised and it has increased greenhouse effect. The atmospheric concentration has increased about 30% since the start of the industrialization in the 19th century. (Fenger & Tjell 2009, p.56)

Particles have many sources and a large variety of sizes, shapes and compositions. In the past, soot from incomplete combustion was the biggest source of particles. Both coarse and fine particles have significant health effects, for example lung diseases and cardiac arrhythmias. It is not quite clear whether the impact is due to the particles as such or compounds attached to them. Today the interest is more focused on fine particles (diameter 10µm or less) from car exhaust. Particles small enough can get deep into the lungs and stay there causing numerous health problems. (McKenna *et al.* 2008, p.3)

Amount of the particle emissions can be reduced by changing the combustion process or by using filters but nonetheless particles might remain a significant urban air quality problem in the future. (Fenger & Tjell 2009, p.55)

2.3. ESP and BHF

The choice of dust collector will depend on many attributes; the most important are the volumetric gas flow, the particle concentration, the particle size distribution and the physical and chemical properties of the particles. Dust collector efficiency depends on the aerodynamic properties of the particle. Terminal velocity is used to define these properties. (Fenger & Tjell 2009, p.79)

According to Fenger & Tjell the most important dust collector systems are:

- Gravity settlers
- Cyclones
- Scrubbers
- Bag house filters
- Electrostatic precipitators

In this thesis only bag house filters and electrostatic precipitators (ESP) are presented and compared more precisely.

2.3.1. Terminal velocity

Terminal velocity is an important characteristic of particles suspended in gas or liquid. At steady state, i.e. zero acceleration, three forces act on suspended particle: gravitational force, drag force and buoyancy. Using force balance the terminal velocity can be calculated. In Stokes' flow regime (for particles in air in the size range 5-50 µm), the terminal velocity V_t can be written as given in the equation below,

$$V_t = \frac{g \cdot d_p^2(\rho_p - \rho_g)}{18\mu} \tag{1}$$

where g is acceleration of gravity, d_p is particle size, ρ_p is particle density, ρ_g is gas density, µ is gas viscosity. Although the equation is exact for the particle range 5-50 µm, it can be used as an accurate approximation also for the particle range 1-100 µm. This size range is very important because the majority of the particles removed from flue gas will be in that interval. Particle sizes with a large terminal velocity are easy to remove from the gas stream. Terminal velocity is proportional to square of the particle size, as seen in Equation 1, meaning that small particles are the most difficult to remove by inertial forces. (Fenger & Tjell 2009, p.80-81)

2.3.2. ESP

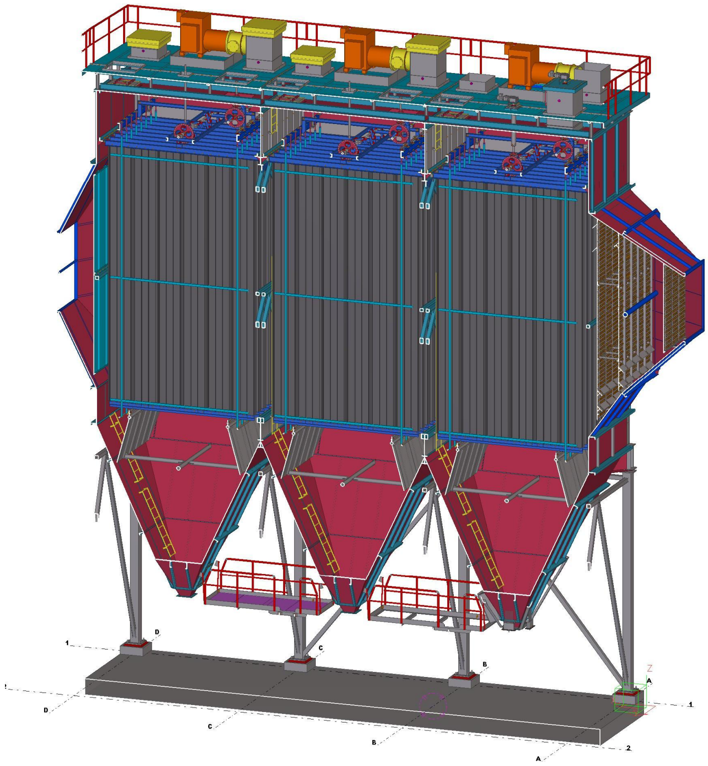

Figure 1. Cross-section of ESP (Valmet training material)

Particle collection by ESP is based on the movement of electrically charged particles in an electrical field. This method is most practical large installations because of the large investment in an electrical field. In ESP collection efficiency for small particles is extremely good because electric force is relatively strong and total efficiency is above 99% for particles in the range of 0.05-200µm. (Fenger & Tjell 2009, p.91)

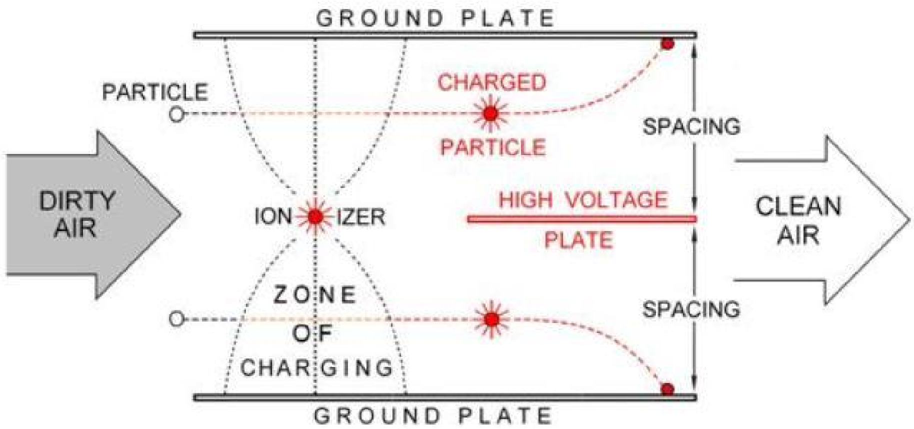

Figure 2. Particle moving through the electric field (Air clean company)

The principle of ESP is that the particles are charged and move in an electric field as shown in Figure 2. ESP consists of a large number of emissions and collecting electrodes. The emissions electrodes are wires and the collecting electrodes are plates. The wires are charged with 20-100 kV (zone of charging) below ground potential and the plates are grounded. The gas flows horizontally between the plates, and the particles in the gas flow are ionized by the corona from the emissions electrodes. Electrically charged particles are pulled from the flow by the strong electrical field and clean air passes through. (McKenna *et al.* 2008, p.135-137)

Fenger & Tjell (2009) describe the principles of ESP as follows:

- The dust particles are charged
- The dust particles move because of the electric field
- The dust particles are collected on the collecting electrodes
- The collected dust is removed from the collecting electrodes

The dust layer from collecting electrodes is removed regularly with a rapping system that vibrates the collecting electrodes. The dust falls to the hopper in the bottom of the precipitator and further into the dust conveyor system.

2.3.3. BHF

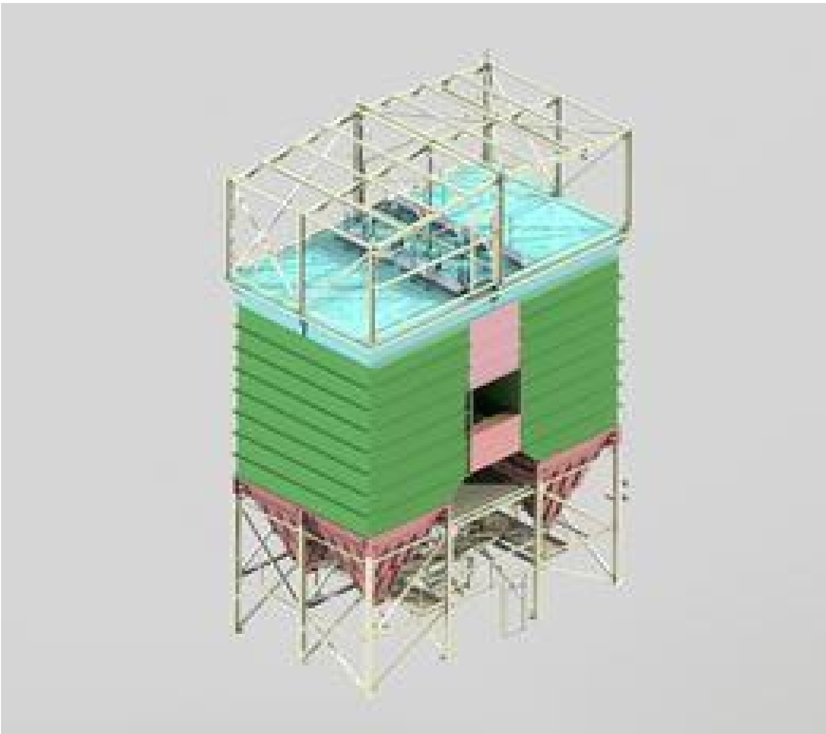

Figure 3. BHF without insulation (Valmet training material)

Filtration is one of the oldest and most widely used methods of separating particles from a gas, and the total efficiency of particle removal may be above 99.9% for all particle sizes. A filter is generally any porous structure that tends to retain the particulate as the carrier gas passes through the fine holes of the filter material. The BHF principle is exactly the same than in a conventional household vacuum cleaner. The structure and the principles of the BHF will be presented more closely in Chapter 7.

2.3.4. ESP and BHF comparison

The choice of the gas cleaning method for particles depends on many parameters. In some cases several different methods can be used at the same time if emission limits are very strict, for example ESP and BHF. Table 3 gives a basic guideline for choosing the methods for further consideration.

Table 3. BHF and ESP comparison (Table is modified based on Fenger & Tjell 2009 and Valmet training material)

	BHF	**ESP**
Temperature limit	200-250 ˚C (higher with metal or ceramic filters)	400-500 ˚C
Influence of water content	Condensation must be avoided	The efficiency depends on the water content
Pressure drop, Pa	1000-1500	50-130
Dust > 10mg/Nm^3	X	X
Dust < 10mg/Nm^3	X	
Heavy metals	X	
Dioxin/Furan	X	
Mercury	X	
Acid gases	X	
Other comments	The optimal choice if a very high efficiency needed, can be used for volumetric gas flows from 0.05 m^3/s up to 500 m^3/s	Not to be used for a gas flow below 5-10 m^3/s because of high investment, dust resistivity must be within certain limits, properties of the particles are important for efficient removal

3. Construction planning

This chapter consists of the basics of project, construction and resource planning.

3.1. Project definition

A project can be defined in many different ways. According to Project Management Institute:" *Project is a temporary endeavor undertaken to create a unique product, service, or result."* (PMI 2004, p.5)

Artto *et al.* define project as a complex unique endeavor with limited costs, scope and time. The goal for a project is also set in advance. (Artto *et al*. 2006, p.26)

Dr. J. M. Juran defines project as a problem scheduled for solution. In this case problem can also be positive. For example, developing a new product is a problem but a positive one. (Ruuska 2013, p.18)

Despite the definition, certain attributes for a project are common; a project is unique effort and project should have definite starting and ending points, a budget, a clearly defined scope or magnitude of work to be done and specific requirements that must be achieved. (Lewis 2006, p.2)

Projects can be divided into different groups by their characters, for example product development, research, investment or delivery project. In this thesis only investment and delivery projects are presented.

Depending from the point of the view, projects can be separated into investment or delivery projects. Although both project types are aiming for the same goal, it is important to make difference between these two projects:

Delivery project is a project where the supplier delivers a product or service according to the client's assignment. A delivery project starts when the contract is signed and ends when the client takes over the object of the project.

Investment project result is often an industrial plant, building or other fixed assets. Material and equipment deliveries are often a significant part of the investment project. A delivery project is often an investment project from the end-client point of view. Usually an investment project includes several subprojects and suppliers/contractors.

Investment and delivery project severability underlines, among other things, the fact that both trading parties have confident information which they do not want to share with each other. Supplier does not reveal project costs and margin target. End-client, on the other hand, does not reveal content of other suppliers' offers and own business objectives. (Artto *et al*. 2006, p.20-21; Pelin 2011, p.34)

3.2. Project life cycle

Projects can be divided into phases which are linked together to provide better management control of the operations that are ongoing. These phases are known as the project life cycle.

Project life cycle generally defines:

- What technical work to do in each phase.
- When the deliverables are to be generated in each phase and how each deliverable is reviewed, verified and validated.
- Who are involved in each phase.
- How to control and approve each phase.

Project life cycle descriptions can be very general or very detailed. After all, few characteristics are common for most project life cycles:

- Phases are generally sequential and are usually defined by some form of technical information or component transfer.
- Cost and personnel levels are low at start, peaking in the middle of the project and dropping rapidly when the project is drawing to a conclusion.
- At the start of the project uncertainty and risk of failing to achieve the objects is greatest. The certainty of completion gradually improves during the project.
- Stakeholders' ability to influence the final characteristics and costs of the project is highest at the start and progressively gets lower as the project continues. Reason for this is a fact that the cost of changes and correcting errors generally increases as the project continues.

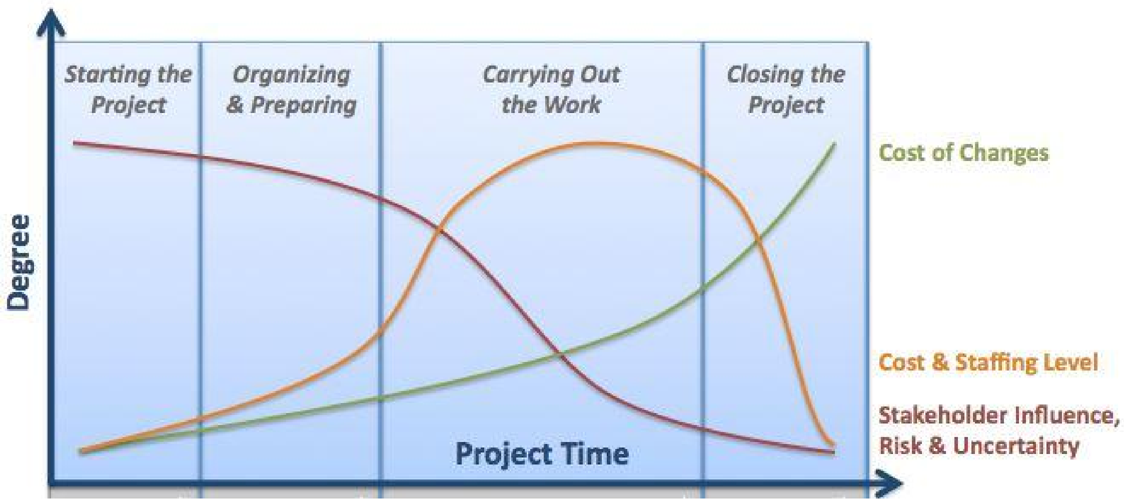

Figure 4. Different factors changes during a project (PMI 2008)

Many project life cycles have similar phase names and deliverables are similar but only few life cycles are similar; Number of phases might vary from four up to nine or even more. Subprojects can have distinct project life cycles, some organizations can have one phase for designing and others can have several divided phases for designing and so on. (PMI 2004, p.19-22)

Hendrickson (2008) has divided the construction project life cycle in the following way (Figure 5). The figure is made from the project owner's point of view and obviously phases are not always strictly sequential. Some of the phases require iteration and others may be carried out in parallel or with overlapping time frames, depending on the nature, size and urgency of the project. Hendrickson has also included operation, maintenance and disposal of facility as part of the project life cycle. It is important for the end-client to take into consideration the life cycle cost of constructed facilities when making choices for a particular project. Saving small amounts of money during construction phase may not be worthwhile if the result is much larger operating and other project life cycle costs. However, estimating costs for the life cycle might be challenging due to the fact that there are many variables to take into account, for example price of the raw materials and energy, inflation etc. (Hendrickson 2008, Chapter 1.2)

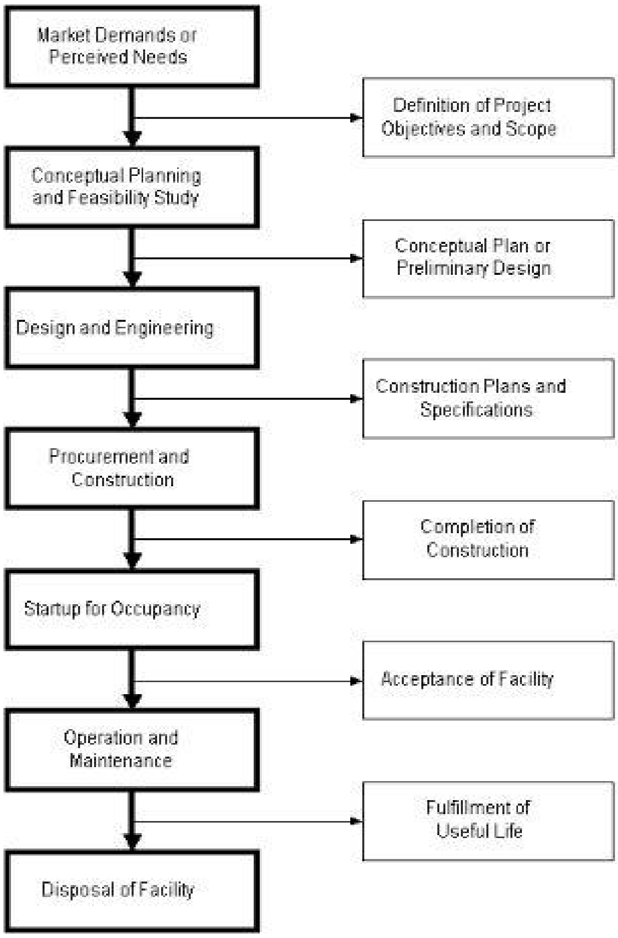

Figure 5. Construction project life cycle (Hendrickson 2008)

3.3. Construction planning

Construction planning is a fundamental and critical function in the management and execution of construction projects. It involves the choice of technology, the definition of work tasks, the estimation of the required resources, durations for individual tasks and recognition of interactions of the work tasks. Construction plan is the basis for developing the budget and schedule for work on the construction site. In addition to these technical aspects, construction planning may also make decisions related to organizations which participate in the project and the extent to which subcontractors will be used in the project. (Hendrickson 2008, Chapter 9.1)

One of the main elements involved in construction planning is to manage and coordinate site operations. This means scheduling the workers in the proper sequence, choosing the most efficient and safe construction techniques, methods, and directing the production process for the building activities. For fluent working on the site, appropriate planning and scheduling needs to be done to order correct materials; ensure an adequate supply of the necessary tools and equipment; and monitor schedule, cost and quality. (Gould & Joyce 2009, p.110-111)

When developing a construction plan, it is typical that either cost or schedule control is emphasized as shown in Figure 6. Some projects are primarily divided into expense categories with associated costs. Construction planning for these projects is mainly cost oriented and costs are divided further into direct and indirect costs. In schedule oriented projects work activities over time are critical, and time is emphasized in the planning process. In these cases, construction plan must include proper precedence among activities that are maintained (*critical path scheduling* procedure) and efficient scheduling of the available resources prevails (*job shop scheduling* procedure). Most complex projects might need mixed planning where both, cost and scheduling planning, are taken into consideration. (Hendrickson 2008, Chapter 9.1)

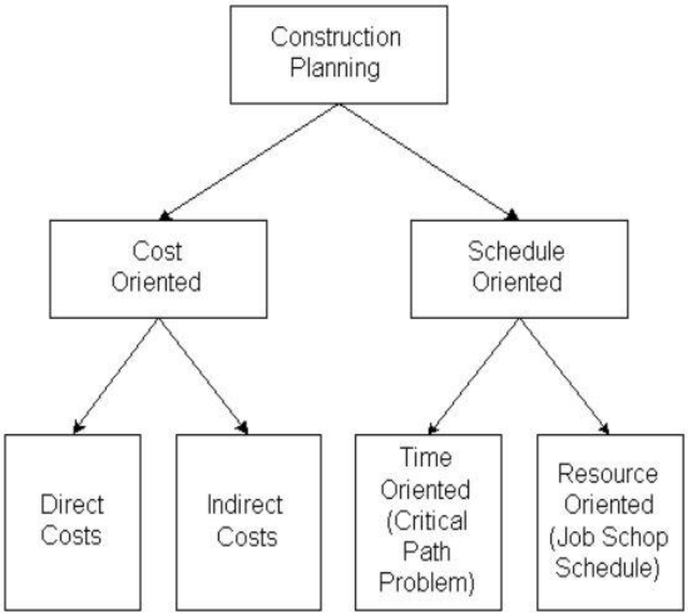

Figure 6. Emphasis in construction planning (Hendrickson 2008)

Valmet ES projects, like all construction projects, are schedule oriented and generally the fastest turnaround is the key for construction planning. For subcontractors it is usually the other way round. They use resource oriented planning because they have certain resources available and scheduling is based on that.

According to Hendrickson (2008), construction planning should be an integral part of the mechanical planning for the whole scope of supply, not limited only for the erection and installation made on the construction site. If the construction planning is included in the mechanical planning, possible adjustments which make erections and installations easier on site can be done. This might save significant amount of time and money.

3.4. Project resource planning

The project schedule and resource planning are interactive processes. In some projects the schedule is decided and after that resources will be put together. This is the case especially when many different companies and subcontractors are involved in the project. It can also be the other way round, a project has certain resources available and the schedule will be made based on the resources. Especially research and product development projects are like this. Common reason for a scheduling failure is that resource planning is neglected or needed resources are not available. This, like all poor planning, might cause major delays and extra expenses in a project. (Pelin 2011, p.143)

Pelin (p.145) has listed the following objectives for resource planning:

- To ensure availability of the planned resources for project and thus securing realization of the schedule.
- Key resource optimization, work load should be continuous and stabile.
- Resource cost optimization.
- Personnel capacity control and adjusting on company level, capacity should meet project’s needs. Also schedule scaling and project prioritization if needed.

Basically, resource planning has two important goals. First, its purpose is to secure that needed resources are available at the right time in the right place. Another important function is to level resources. This means that resources are used as effectively and smoothly as possible during the project. For example, if different tasks are depending on each other’s resources, those tasks cannot carried out simultaneously. It is obvious that the same person or machine cannot be in two different places at the same time. Resource planning is a very complex multivariate optimization problem because different resources have different needs and limitations. In the planning phase it would be ideal to find balance between optimal schedule and costs caused by the delays and needed extra resources. (Artto *et al.* 2006, p.144-145)

Pelin (p.146) and Artto *et al.* (p.141-142) have divided resource needs into different groups:

- *Human resources:* Personnel and especially their knowhow is the key resource because it is a major factor affecting the project schedule. Partner and subcontracting relations have become essential part of today’s project organizations. When making human resource planning it is important to keep in mind that not all the weekdays during a year are “effective”. There are 260 weekdays in a year but, for example on the construction site, only approximately 200 days in a year workers are working.
- *Facilities:* Facilities needed in implementing the project such as offices, laboratories etc. should be recognized as part of the resource planning. Particularly the availability of facilities possessed by some other company should be ensured.
- *Machinery:* Similar requirements as with facilities, it should be definitely planned what kind of machinery is needed and when
- *Money:* Money is needed to cover project expenses and funding of the project must be closely planned before project starts.
- *Materials:* Materials refer to all the raw materials, machinery and components needed for products and any substantial output. Services bought from subcontractors are often considered as material sourcing.

4. HSE

In this chapter the major lines of the Valmet HSE are presented. HSE plays a major role in today's construction business, and customers have become more demanding regarding HSE matters.

4.1. HSE at Valmet

"Valmet is committed to the safety and wellbeing of our employees, customers and partners. We are all responsible. Together, we take safety forward." - Pasi Laine, Valmet's President and CEO.

Valmet is committed to improve the health, safety and environmental performance of its operations and the goal is zero harm. Valmet wants to provide a safe working environment and minimize the environmental impact.

According to Valmet's HSE policy, compliance with local laws is only a minimum requirement. Valmet has defined minimum requirements at work for high-risk activities to ensure common practices for all its operations. The goal is to work proactively to create incident-free workplace. One important thing considering proactively working is that all the risks, hazards and near misses are actively reported. Learning from near misses prevent making the same mistake again and accidents can be avoided more effectively beforehand. Every Valmet or subcontractors worker must accomplish "minimum safety standards training" before working at any Valmet construction site. This is one practical example how the zero accident practice is implemented. (Valmet public internet site)

Lost time incident rate (LTIF) (Lost time incidents per 1.000.000 working hours)	4
Total recordable incident rate (TRIF) (LTIF + medical treatment and restricted work cases)	8
Near miss and risk observations	1 / employee / year
HSE training	8h / employee / year
Number of documented safety inspections per million whrs	150

Figure 7. Valmet health and safety targets for 2015 (Valmet public internet site)

In the environmental responsibility area, Valmet's focus is in developing environmental technologies and offering eco-efficient solutions to the customers. Valmet environmental business consists of products and services that improve environmental performance of the customers. In addition, Valmet strives to minimize own environmental footprint by improving energy efficiency and waste management practices in all locations. (Valmet public internet site)

Indicators (rolling 12 months)	Target 2015	Target 2020
Energy consumption and CO_2 emissions reduction (% reduction in yearly consumption compared to net sales, baseline reference yearly average 2005–2009)	15%	20%
Municipal water consumption reduction (% reduction in yearly consumption compared to net sales, baseline reference yearly average 2011–2012)		15%
Total waste amount reduction (% reduction in yearly amounts compared to net sales, baseline reference yearly average 2011–2012)		15%
Waste utilisation rate (%) (% increase in waste utilisation (recycled waste + incineration / total waste), baseline reference yearly average 2011–2012)		10%

Figure 8. Valmet environmental efficiency targets (Valmet public internet site)

4.2. HSE at construction site

The basis of Valmet site operation is to perform the erection project in such a way as to not endanger the safety or health of project workers, mill personnel or guests nor cause extra waste or emissions to the environment. Valmet's policy for health, safety and environment shall be complied within the project. The project shall act in full compliance with local laws: the destination country of the delivery and EU legislation.

Valmet and its subcontractors have responsibility of their own employees and site health, safety and environmental aspects of the project during erection and commissioning for Valmet's working area.

All Valmet personnel and subcontractors shall be aware of their duties. Site specific health and safety rules are set by the client and Valmet. HSE instructions, including the HSE manual and management system, shall be complied within Valmet's working areas. Details shall be provided to subcontractors at site when applicable. (Valmet HSE material)

4.2.1. Safety management at site

Valmet site manager is responsible for Valmet's safety activities at site. It is site manager's responsibility to ensure safe systems of work and that risk assessments are prepared in advance and approved before work being undertaken.

Site manager's responsibilities include:

- Ensure that safe working practices and instructions are adopted and provide sufficient resources to ensure that suitable control measures, including personal protective equipment, are implemented.
- Support the implementation of the site safety policy, support the aims of the safety policy and encourage improvements.
- Take part to plan preventative measures to prevent re-occurrence of accidents and unsafe practices.
- Chair Valmet Internal weekly safety meetings with Valmet site management.

Usually Valmet has a HSE specialist at site, who assists the site manager in every day routines. The HSE specialist's tasks include for example the following tasks:

- Giving of Valmet induction
- Checking risk assessments, method statements, and permits validity
- Incident investigation
- Daily observation of work is conducted according set rules
- Identifying on a daily basis unsafe situations and unsafe acts
- Taking immediate action to correct these situations or initiate corrective measures
- Advising all levels of the project organization on HSE matters

4.2.2. Employees training and duties

All the employees shall be trained on the contents of the Site HSE Plan, other HSE instructions concerning the site and the risk assessments made for their work. Each subcontractor shall provide a sufficient number of personal protective equipment for their personnel on site and supervise their use.

All employees engaged on work at site are obliged to ensure that their work does not pose a risk to other persons engaged.

Some of the rules for safe working at site are listed below:

- Using correct materials, tools and methods.
- Taking care of and maintain the safety of equipment and tools.
- Reporting all unsafe conditions and deficiencies on plant and equipment immediately to their foreman.
- Avoiding any behavior that could endanger them and their colleagues.
- Maintaining a clean working environment.
- Having the correct education or experience to execute the given job.
- Taking part in risk assessments as required.
- Reporting all incidents and near misses immediately to their foreman.
- Having the right and duty to intervene if HSE is being compromised.
- Everyone is authorized to stop and take out service equipment, machines and tools for safety reasons in case immediate hazards exist for personnel and/or environment.
- Being under influence or using drugs and alcohol has a zero tolerance at site.

5. Lean

This chapter focuses on the Lean philosophy. History and principles of Lean are presented as well as some of its tools which are applicable in construction planning.

5.1. Definition and history of Lean

"All we are doing is looking at the time line, from the moment the customer gives us an order to the point when we collect the cash. And we are reducing the time line by reducing the non-value adding wastes." (Liker 2004)

-Taiichi Ohno

There are multiple descriptions for Lean. Womack *et al*. (1990) describe Lean as a systematic approach that focuses the entire enterprise on continuously improving quality, cost, delivery and safety by seeking to eliminate waste, create flow and increase the velocity of the system's ability to meet customer's demand. In other words, Lean is the production system that combines the advantages of craft and mass production, avoiding the high cost of craft and the rigidity of the mass production. Lean producers employ teams of multi-skilled workers at all levels of the organization and use highly flexible, increasingly automated machines to produce a huge range of products in enormous volumes.

John Krafcik, the IVMP researcher who invented the term Lean, says it is called simply "Lean" because it needs less of everything compared with mass production for example inventory, human effort in the factory, manufacturing space etc.

Some of the methods of Lean, first known as Toyota Production System (TPS), are based on the ideas of Fredrick Winslow Taylor, the father of industrial and systems engineering. Kiichiro Toyoda, who founded Toyota in 1937, studied the ideas of Taylor, Henry Ford and W. Edward Demming when trying to develop his company. This resulted in creation and refinement of Toyota Production System between 1948 and 1975 by Taiichi Ohno, Shigeo Shingo and Eiji Toyoda. (Allen 2010, p.10, 122)

In 1940s, after World War II, Toyota was known for their textile machinery and had made only few trucks for military before. They were determined to go into full-scale car and commercial truck manufacturing but they faced several problems:

- *Small domestic markets.* The domestic market was tiny but the range for demanded cars was wide, from luxury cars to large trucks.
- *Lack of cheap work force.* The native Japanese work force had become more demanding. New labor laws were introduced by the American occupation and workers were able to negotiate more favorable conditions of employment. In addition, in Japan, there were no temporary immigrants or minorities with limited occupational choices.

These groups formed the core of the working force for mass-production in the USA and other Western countries.

- *Economy of Japan*. Economy was in ruins after World War II, and companies in Japan were starving for capital and foreign exchange. Because of these facts, purchasing latest Western production technology was nearly impossible.
- *Market protection*. The outside world was full of motor-vehicle producers who were interested in investing to Japan to establish operations there. They also wanted to protect their established markets from the Japanese exports. (Womack et al. 1990, p.48-50)

After World War II Kiichiro Toyoda and Taiichi Ohno started to rethink and rebuild Toyota's way to produce cars. It was realized that workers are more pleased and productive if they are given more responsibilities considering their own work. One of the first changes that was made, was to group workers into teams with a team leader rather than a foreman. Teams were given their piece of assembly line, and they were told to work together and find their own best way to complete tasks. Teams were also given a job of housekeeping, minor repairs and quality checking. When the teams were running smoothly, teams were periodically asked to suggest ways to improve the process. This continuous and incremental improvement process, *kaizen* in Japanese, took place in collaboration with the industrial engineers. Process is also known as continuous improvement, one of the cornerstones of Lean thinking. (Womack et al. 1990, p.55-56)

5.2. Lean principles

To understand how to apply Lean in any organization, following five principles must be studied:

1. Identify value

The critical starting point for Lean is *value*. Value can only be defined by the ultimate customer. And it is only meaningful when expressed in the terms of a specific product which meets the customer's needs at a specific price at a specific time. Value is created by the producer. From the customer's standpoint, this is why producers exist. (Womack & Jones 1996, p.16)

2. Map the value stream

The *value stream* is the combination of the actions required to bring certain product (whether a good, a service or a combination of these two) through the three critical tasks of any business:

- The problem-solving task running from concept through detailed design and engineering to production launch.

- The information task running from order-taking through detailed scheduling to delivery.
- The physical transformation task proceeding from raw materials to a finished product.

Realizing and identifying the entire value stream for each product is the next step in Lean. This step is rarely taken in organizations, but where it is attempted it usually exposes enormous amount of waste.

Value stream analysis almost always shows that three types of actions are occurring along the value stream; many steps will be found to clearly create value, many other steps will be found to create no value but are unavoidable with current technologies and production assets, many steps will be found not to create any value and are immediately avoidable. (Womack & Jones 1996, p.19-21)

3. Create flow

When the value has been specified for a certain product, value stream is identified and obvious wasteful steps eliminated. Next step is to make the remaining, value-creating step *flow.* This might be the most difficult step because it re-arranges the way of thinking in many ways. When making a value flow, the thing is to focus on the actual product. The second phase is to ignore the traditional boundaries of jobs, careers, functions etc. to form Lean enterprise removing all impediments to the continuous flow of the specific product. The third phase is to rethink specific work practices and eliminate backflows, scrap and stoppages of all sorts so that the design, order, and production of the specific product can proceed continuously. (Womack & Jones 1996, p.50-52)

4. Establish pull

Pull in simplest terms means that do not produce any good until customer asks for it. Obviously, in reality, following this practice is a bit more complicated. Maybe one way to understand the logic and challenge of pull thinking is to start with the customer. The customer has the need for a product, and then the producer starts to work backwards the steps required to bring the desired product to the customer. If the pull thinking works perfectly, the producer can design, schedule and make exactly what the customer wants just when the customer wants. The customer pulls the product from the company as needed rather than the company pushing the products onto the customer. (Womack & Jones 1996, p.24, 67-68)

5. Seek perfection

The final principle of the Lean thinking is *perfection*. In theory perfection is possible to accomplish because the preceding four steps interact with each other in a circle. Getting value to flow faster always exposes hidden waste in the value stream. And the harder pulling, the more impediments to flow are revealed and they can be removed. (Womack & Jones 1996, p.25)

Figure 9. Lean principles (Lean Enterprise Institute)

Lean strives for the absolute elimination of waste, overburden and unevenness in all areas to allow manufacturer to work smoothly and efficiently. Japanese definition for the waste is; anything other than the minimum amount of equipment, materials, parts and working time absolutely essential to production. Americans define the waste in bit different way, from the adding value perspective; anything other than the absolute minimum resources of material, machines and manpower required to add value to the product is waste. (Hay 1988, p.15-17)

Toyoda and Ohno have identified seven types of, *waste*, muda in business operations and production processes. The eighth type of waste, underutilization of worker skills, was added later, first seven are the original types of waste.

- *Overproduction.* Manufacturing products in advance or excess. Causes hiring of unnecessary staff, rising of storage and transportation costs in consequence of too large inventory.
- *Waiting.* Time is wasted when workers have to wait for something; one process begins while another finishes, tool, component, delivery etc. Or workers simply are out of work due to delays in process, caused by several reasons e.g. bottle necks in process, lack of materials, shutting down of machinery. According to some estimates, as much as 99 percent of a product's time in manufacture is actually spent waiting.
- *Transportation*. Transportation of incomplete products, material or parts between processes and warehouses. Moving products around adds no value, is expensive and can cause damage or product deterioration.
- *Inapprotiate processing.* Ineffective use of tools, poor handling of parts due to poor designing cause useless movement and delays in production. Using expensive equipment is wasteful if simpler machinery would work as well, and doing excessively good quality is waste, more important is to produce sufficient quality.

- *Excessive inventory.* Excess raw materials, incomplete or finished products increase lead times and consume productive floor space. Storages also cause delays, damaged products and increased costs. Excess inventory tends to hide problems in process for example delayed deliveries from subcontractors, machinery down time and prolonged assembly times.
- *Unnecessary movement.* All the useless movement, as workers have to bend, reach, search, lift or walk distances to do their jobs, is waste of resources.
- *Defects.* Quality defects resulting in re-work, wreck, guarantee issues, rescheduling and capacity loss are a huge cost to organizations. In many organizations the total cost of defects is often a significant percentage of total manufacturing cost.
- *Underutilization of worker skills.* Waste of ideas, skills, improvements and learning opportunities if workers are not listened to or engaged properly. Although workers are hired for a specific skill set, they always bring other skills and insights to the workplace that should be acknowledged and utilized.

Overproduction is considered as the most important type of waste because it causes most of the other wastes. Overproduction at any stage in process increases inventory, useless transportation and so on. (Allen 2010, p.28-29)

5.3. DFMA

5.3.1. Principles of DFMA

The principal contributor to the development of modern production and assembly methods was Henry Ford. He described his principles of assembly in the following words:” Place the tools and then the men in the sequence of the operations so that each part shall travel the least distance while in the process of finishing. Use work slides or some other form of carrier so that when a workman completes his operation he drops the part always in the same place which must always be the most convenient place to his hand – and if possible, have gravity carry the part to the next workman. Use sliding assembly lines by which parts to be assembled are delivered at convenient intervals, spaced to make it easier to work on them.” (Boothroyd 2005, p.3)

Design for Manufacture and Assembly (DFMA) is a combination of two methodologies; Design for Manufacture (DFM), which means the design for ease of manufacture of the product’s parts, and Design for Assembly (DFA), which means the design of the product for ease of assembly. DFMA is used as the basis to provide guidance for the design process in simplifying the product structure, to reduce manufacturing and assembly costs and to quantify improvements. The practice of applying DFMA is to identify, quantify and eliminate waste or inefficiency in a product design and therefore it is one tool of the Lean.

DFMA should be considered at all stages of the design process but especially during early stages. When designers start working with new ideas, they should give serious consideration to the ease of manufacture and assembly of the product or sub-assembly during production and service. Usually production cost and performance are well analyzed during the design process but analysis for product assemblability should also be routinely performed.

During the design process, designers may need to factor many variables in their thinking and make several compromises with respect to performance, cost, reliability and other attributes. Compared to these concerns, manufacture and assembly costs tend to be difficult for designers to define and therefore are not receiving enough attention. (Boothroyd 2005, p.220-221)

Designers have to understand the importance of manufacturability of a product to be able to design competitive products. Several design guidelines have been introduced for designers' assistance to design easier manufacturable and assemblable products. The following DFMA guidelines are developed by Professor Henry Stoll:

- *Reduce the total number of parts.* Probably the most effective way to reduce manufacturing costs. In general, it reduces the level of intensity of all activities related to the product during its lifespan for example less purchases, development and engineering time, testing etc.
- *Develop a modular design.* The use of modules in product design simplifies manufacturing activities such as inspection, testing, assembly, maintenance and so on. Also adds versatility to product update in the redesign process, and helps running tests before the final assembly is put together.
- *Use of standard components.* Standard components are less expensive, better available and reliability factors are better ascertained compared to the custom-made items.
- *Design parts to be multi-functional.* Multi-functional parts reduce the total number of parts in design.
- *Design parts for multi-use.* These parts can have the same or different functions when used in different products.
- *Design for ease of fabrication.* Selection of the optimal combination between the material and fabrication process to minimize the overall manufacturing costs. Finalizing operations such as painting, polishing, finish machining etc. should be avoided if possible.
- *Avoid separate fasteners.* The use of fasteners increases the costs of manufacturing due to the handling and feeding operations that have to be performed.

- *Minimize assembly directions.* All parts should be assembled from one direction, preferably from above.
- *Maximize compliance.* Errors can occur during erection and assembly operations due to variations in part dimensions. For this reason, it is necessary to include compliance in the part design and in the assembly process.
- *Minimize handling.* Handling consists of positioning, orienting, and fixing a part or component. (The University of New Mexico)

5.3.2. Different level of product development

One of the most important elements of DFMA is co-operation with designers and people who are responsible for manufacturing. Links between product designing and manufacturing can be seen on many different levels. The product development can be divided into four different levels, and all products have implications on all four levels, whether they are considered or not. (Lempiäinen & Savolainen 2003, p.16)

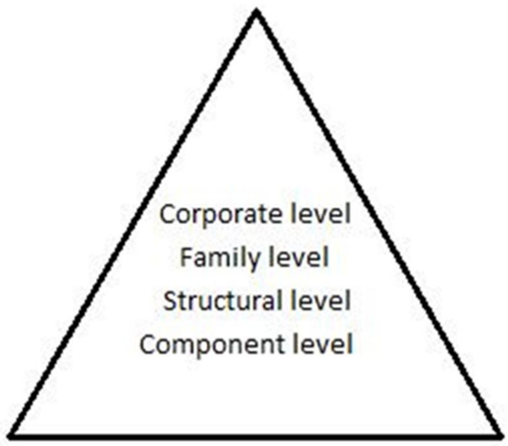

Figure 10. Levels of product development process (Lempiäinen & Savolainen 2003)

Corporate level. The highest level of the hierarchy is the corporate level. On the corporate level, the designed product is researched and compared with other company's products. On this level, the company will ensure that there is no overlapping in product developing and manufacturing in different sections of the company. Intention is also to find out if it possible to use the same technical solutions for different products within the company. The corporate level is close to the company's strategic planning and therefore it largely defines the future of the company.

Family level. On the product family level different product variants are compared, and the product launching details are decided. This level planning mainly defines product's lifespan on the market. Family level works also as a base for a new product and often new products are developed by scaling existing products to more efficient and powerful.

Structural level. On the structural level the goal is to understand how product's structure and production processes fit together. Production process consists of separated functions, such as parts production, assembly, testing, packing and supporting activities. Designers can use known critical section, for example testing, as a starting point for a new product development. For example, product testability can be simplified by combining product structures to sub-assemblies. The internal cost distribution can reveal the components, which are the most critical ones for manufacturing costs. Comparing similar products from different companies may expose areas where own product critically differs from others.

Component level. On this level all the detail level decisions are made for each individual components. The component level is the area where everyone involved in the designing process has an opinion. To save development time and resources it is useful to concentrate on critical components in terms of cost, time, reject rate or other known problem related components. On the component level one must be aware of new manufacturing methods which have been developed after the previous designing project. In many cases, it is a good idea to let the suppliers to take care of component developments because they have the best knowledge of the manufacturing operations. Component level's primary target is to ensure that the yield of components is secured. (Lempiäinen & Savolainen 2003, p.16-19)

5.3.3. Criteria for manufacturability

The goal for DFMA is to design a product that is easily and economically manufactured. The importance of designing for manufacturing is underlined by the fact that about 70-80% of manufacturing costs of the product (cost of materials, processing and assembly) are determined and committed during developing and planning phases. Product decision (process planning and machine tool selection) is responsible only for 20-30% of the production costs. (The University of New Mexico)

Production costs are often considered as a good benchmark for manufacturability. It is important to keep in mind that costs are only one parameter. If focused on only low production costs, other product attributes may suffer, for example quality or lead-time. Several different criteria need to be taken into consideration when evaluating product manufacturability. The purpose of these different criteria for manufacturability is to create a base for evaluation and to avoid conflicts between different areas. It is important to notice that difficulties on one area can be solved through other areas, for example a quality problem can be fixed by using better raw materials.

Product design has an effect on every area listed below. For that reason, seven criteria listed below are suitable for comparing different options as well as to clarify the goal of the product development project. The fact, often forgotten in a design process, is the ability to design a product which causes low fixed cost as well as designing a product causing low variable cost. (Lempiäinen & Savolainen 2003, p.20-21)

Criteria for manufacturability according to Lempiäinen & Savolainen (2003):

Quality. Product’s capability to meet specifications and expectations. Lack of quality causes quality control problems, repairs and wrecking at the workshop. Quality problems may go through the whole quality control system causing expensive guarantee issues and product withdrawal from the market.

Production costs. Costs are divided into fixed and variable costs. Fixed costs do not change with an increase or decrease in the amount of goods produced: warehousing, quality control, production facilities etc. Variable costs vary in relation to changes in the volume of activity: raw materials, used working hours etc.

Flexibility. Easiness to adapt wanted changes into the product.

Risk. Continuous risks involved in production.

Lead-time. Ability to reach quick lead-time in production for standard and customized products.

Effectiveness. Effective use of personnel and economic resources.

Environmental issues. Including following matters; environmental effects of the production process, recyclability of materials and product dismantle. (Lempiäinen & Savolainen 2003, p.20-21)

6. Schedule planning

In this chapter the principles and techniques for schedule planning are presented. Especially the Work Breakdown Structure method and its components are studied more precisely.

6.1. Schedule planning principles

Projects are generally complex endeavors and a schedule is essential to guide the execution of the project. Scheduling is the determination of the timing and sequence of operations in the project and their assembly to give the overall completion time. Scheduling focuses on one part in project planning and it answers the questions *what* and *when* something happens in a project. Project main schedule is also basis for resource planning. The execution of a project proceeds rarely as initially planned, and the schedule often requires reassessment during the project. Control of the schedule lasts through the whole project, and it is important that the estimated and realized schedule is analyzed to improve the scheduling process for forthcoming projects. (Lindberg *et al.* 2012, p.27-35)

A well planned schedule is also a major factor for profitability of the project. In most cases, project budget excess is caused by the costs considering catching up the failed schedule. (Pelin 2011, p.106)

There are several stakeholders involved in a project. They all need and benefit from project scheduling but from the different perspectives. Saleh Mubarak (2010) lists reasons and benefits for scheduling for different stakeholders but in this thesis only contractor perspective is presented:

Calculate the project completion date. In most construction projects, the general contractor and its subcontractors are obligated to finish the project by a certain date specified in the contract. This might be the most obvious reason for making a schedule for the project.

Calculate the start or end of a specific activity. Specific activities may require special attention, such as ordering and delivering materials or equipment, for example delivery of very large items may need some special arrangements. Also, useless storing should be avoided on construction site and just-in-time delivery for materials is recommended.

Coordinate subcontractors. The general contractor's role on a construction site is mostly to coordinate actions of different subcontractors. The use of tower cranes and other equipment and ensuring that adequate work space is available for all subcontractors, are among tasks that need to be closely coordinated on the site.

Predict and calculate the cash flow. The timing of an activity has an impact on the cash flow. The end-client, general contractor and subcontractors have agreed certain milestones regarding payments of their scope of supplies.

Improve work efficiency. Efficient workers and materials management can save money and time for contractors.

Serve as an effective project control tool. Project control is achieved by comparing the actual schedule and budget with the as-planned schedule and budget.

Evaluate the effect of changes. Change orders are almost inevitable in construction projects. Those may come as an order to the contractor or request for evaluation before execution. A change may be an addition, a deletion or a substitution, and most likely it will have impact on the budget or schedule. The contractor's responsibility is to inform the end-client on impacts and obtain an approval for the change.

Prove delay claims. Like change orders, delay claims are also common in construction projects. Contractors must accurately prove their claims against the end-client (or general contractor) using project schedules.

6.2. Techniques for schedule planning

Several techniques and tools are developed for schedule planning and in this chapter the most common of them are introduced. Artto *et al.* (2006) state that schedule planning and control has become an essential object for research in the project management. The vast majority of techniques for the schedule planning is based on the Work Breakdown Structure (WBS).

Schedule planning phases for a contractor are (Dykstra 2011, p.286):

1. Identify work activities

2. Sequence the work activities

3. Estimate activity durations

4. Hand-draw the schedule and input the data into computer

Gould & Joyce (2009) have similar ideas but they have added two phases to the list:

5. Revise and adjust

6. Monitor and control

In practice schedule planning is an iterative process where observations or project changes at later phases might cause changes related to decisions made earlier in the project. Also the importance of different schedule phases depends on the perspective. For example construction companies have certain resources at their disposal and therefore scheduling process is heavily resource dependent. Schedule planning aiming to shortest possible lead time, estimating activity durations and sequencing the work activities are in significant role. Due to fact that projects vary from each other the list above and its order cannot be reckoned a fixed and suitable description for schedule planning in every cases. (Knuuttila 2012, s.16)

6.2.1. Identify work activities

First step in creating the schedule is to create a list of work activities that can be organized and controlled. The Work Breakdown Structure (WBS) is a hierarchical and incremental decomposition of the project into smaller tasks and work packages to meet project objectives. Those smaller tasks are easier to manage in terms of size, duration, costs and responsibility. The work breakdown structure provides a common framework for the natural development of the overall planning and control of the project. WBS answers the question: "What has to be accomplished in the project?" (Kettunen 2009, p.66-67)

According to Pelin (p.90-91) WBS objectives can be summarized as follows:

- WBS phases the project and in every phase the breakdown structure can be different.
- WBS divides the project into definite liability entities and sub-projects.
- WBS divides project schedules into separate sub-schedules with subscribed dependencies.
- WBS creates framework for cost control by defining monitored cost items (work packages)
- WBS sets hierarchical outline and coding for the project (WBS numbers)
- WBS integrates temporal and economic planning and control of the project

There are different approaches to create WBS but often one of these three approaches is used. *The top-down approach* might be the most typical approach to create WBS. It begins with the final or largest deliverables. All components that make up these deliverables are identified. This process continues to greater and greater detail until all work packages are identified. It is very difficult for the project manager or another member of the project to do this alone. Usually input from other members is needed, especially as project activities are divided into more detailed work packages.

The bottom-up approach involves intense team participation. Members of the project begin by identifying as many specific tasks as possible. After that they gather these tasks into larger project activities. These project activities may be grouped into more extensive activities, until the final deliverables for the project are planned. This approach can be very effective for scope and schedule planning because it can potentially involve input and consensus from the entire project team. For the same reasons, it can be a very time consuming process for putting together WBS.

The analogy approach uses a similar WBS as a starting point. This method can be effective if loads of similar kind of projects are made for the same client. Such an approach is greatly facilitated if the firm keeps good records and has archives of past projects. (The Pennsylvania State University)

WBS can consist of different structures or categorizations due to different situations and cultures in the companies. Commonly the following kind of basic structure or a combination of several structures are used:

- *Project phase:* WBS is divided into successive phases of the project. The project is chronologically divided into limited independent parts. The project phases can be for example planning, execution and commissioning etc.
- *Systems:* WBS is separated into systems used in the project. The system is a functionally discrete thing that is joined to the project organization horizontally.
- *Organizational:* WBS is divided into organizational types of work in the project such as project management, engineering, erection, inspections etc.
- *Structural:* WBS is broken down to different physical parts of the project. In a large project, WBS can be broken down into geographically separated items such as buildings. It is further divided into smaller items e.g. different parts of the building. Structural categorization is always involved in WBS. (Artto *et al.* 2006, p.114-115; Pelin 2011, p.93)

After the approach and categorization for WBS is decided, it can be broken down into different levels. Project complexity and customer expectations, among other criteria, are considered in determining the number of levels in a work breakdown structure. Some basic rules should be taken into consideration when the number of levels is decided. Level 1, the top objective, always represents the whole scope of the project. Ideally level 2 would be ideal have about 10 subprojects. Those subprojects should be easily manageable and a usable basis for planning, controlling and reporting. On the following levels, 3 and so on, about 10 subtasks or work packages for every upper level tasks would be optimal. Typically there are three to five levels in a WBS and it might vary greatly depending on the project. Main purpose for breaking down the project into different levels is that all the applicable tasks are taken into consideration. Also, it gives project members a better view of what it takes to accomplish the scope of the project, and even very large projects will be easier to realize and control. (Artto *et al*. 2006, p.115-116)

After the WBS is broken down into levels, those levels are encoded into hierarchical structure. The coding is structured in a way that it is easy to figure out which work package is connected to a certain higher level task. (Pelin 2011, p.93)

WBS-level 1 = project 1.0.0
WBS-level 2 = subtask 1.1.0
WBS-level 3 = work package 1.1.1

Level 1	Level 2	Level 3
1.Boiler K-1		
	1.1 SCR reactor erection	
		1.1.1 SCR installation
		1.1.2 SCR catalyst blocks installation
	1.2 Ducts and dampers erection	
		1.2.1 Foundations for new IDF
		1.2.2 LUVO installation

Figure 11. Different project levels, subtasks and work packages with WBS-code

6.2.2. Sequence the work activities

Once activities have been identified, the order in which the activities will be completed must be determined. Every activity has a logical sequence in the overall work and, unless an activity starts or ends the project, each has activities that come before and after it.

Pelin (2011) has divided dependencies between tasks in the following way:

Logical dependency. Most common type of dependency. Tasks can be accomplished only in certain order.

Overlapping. Start of a task depends on other task's particular phase.

Delay dependency. Certain time gap must exist between tasks.

Resource constraints. Tasks can be done simultaneously but they need the same resources.

Calendar dependency. Start and end of the task is bound to a certain time of the year. Nuclear and other power plants shutdowns are usually scheduled in the middle of the summer when the power consumption is lowest.

No direct dependency. Some tasks are not dependent on other tasks in the project. Those tasks can be done when it is most favorable for the project.

When considering the order of tasks, their dependencies with each other must be carefully considered.

6.2.3. Estimate activity durations

At this point the duration of each activity must be determined. Duration is the time needed to complete an activity. On most projects time is defined in days, activities are too broad to fit conveniently into hourly units but too small to fit into weekly units on the schedule.

The primary consideration used for determining activity durations are the total available time, the available resources and expected levels of productivity. At this stage it is reasonable to calculate the normal duration for each activity; the duration in which this activity is completed in the most effective manners. In most cases estimations are done by the experts, and data gathered from previous projects is essential to get best possible approximation. After all, activity durations are estimates and can be inaccurate for many reasons, for example, quantity of work is miscalculated, workers are not as productive as planned, lack of necessary equipment and so on. (Artto *et al*. 2006, p.128; Dykstra 2011, p.290)

6.2.4. Hand-draw the schedule and input the data into computer

Hand-drawing of a rough network diagram on a large paper is recommended so that the overall logic and dependences between different tasks can be viewed. Easiest way to draw by hand is an activity-on-node (AON) type of network diagram. Each node represents a single activity and it is connected by arrows to those with which it has an immediate dependency. These dependencies, or linkages, make up the job logic. Drawing a simple network diagram enables the schedule planner to identify gaps or mistakes in how the job has been laid out and enables adjustments to be made. The computer cannot pick up mistakes in logic; inputting data from a hand-drawn rough schedule leads to a more accurate final schedule. (Dykstra 2011, p.290-292)

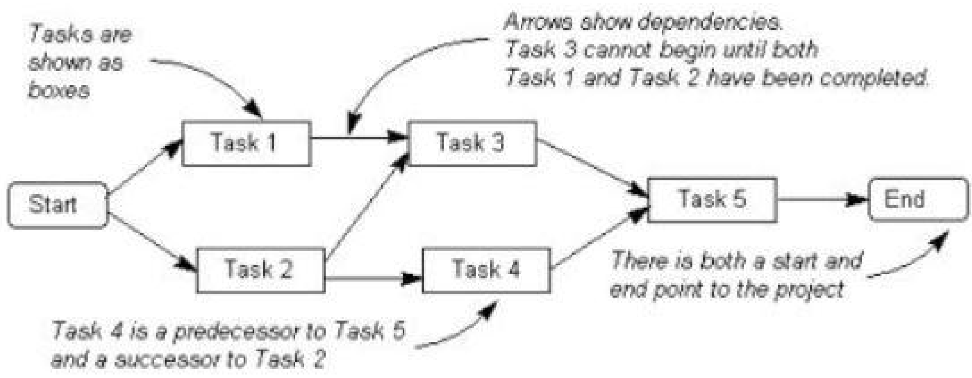

Figure 12. AON type of network diagram (Tutorialspoint)

Linkages between tasks in network diagram are shown in Figure 13. (Dykstra 2011, p.294):

Finish-to-Start. An activity cannot begin until its predecessor is finished.

Finish-to-Finish. Activities can be finished at the same time.

Start-to-Start. Activities can start together.

Start-to-Finish. The start of an activity ends other activity.

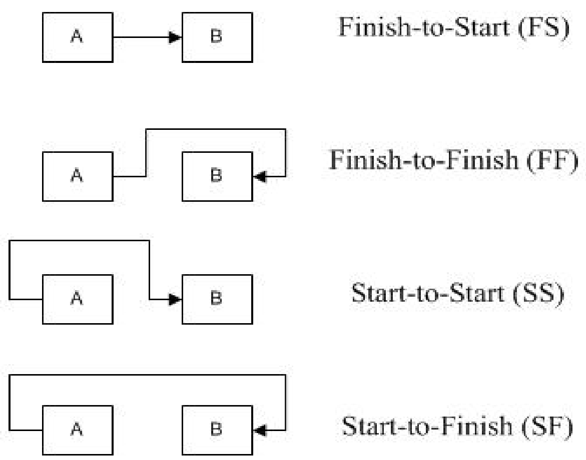

Figure 13. Network diagram linkages between tasks (Construction engineering and management)

Network diagram can also depict project's critical path. The critical path identifies the activities, which if delayed, will delay the entire project. Every project has at least one critical path. Figure 14 shows the critical path by a darkened line. There are two separate activity paths on this diagram. The top path extends from start through tasks 1, 2 and 3 and is completed at the finish. The bottom path includes tasks 4, 5 and 3. All tasks' durations are indicated under each task in days. As shown in the Figure 14, this project's critical path is the path on the top, totaling 9 days. This means that the project cannot be possibly completed in less than 9 days and any delay along the top path extend that time. Any delay up to two days along the bottom path can be absorbed without delaying the entire project. These extra days are called float and obviously the critical path has no float. (Dykstra 2011, p.295)

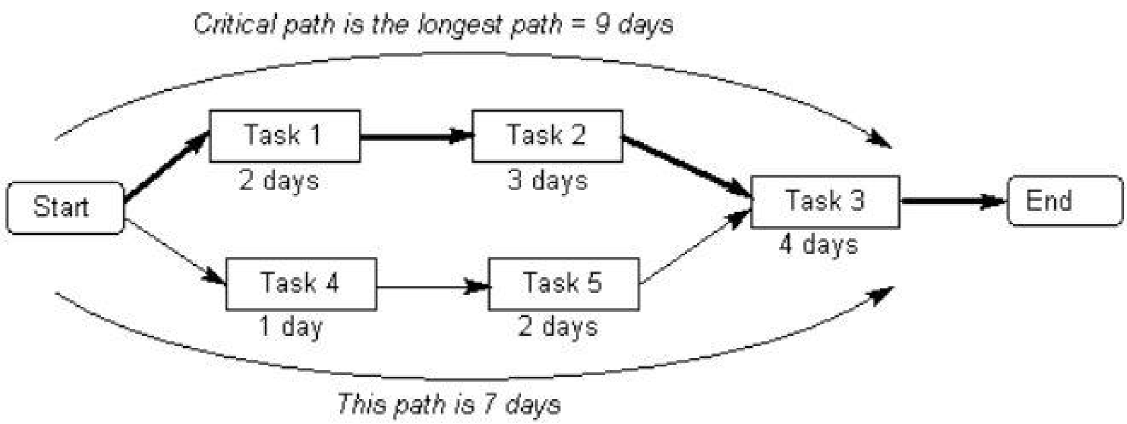

Figure 14. Critical path method (Syque)

6.2.5. Revise and adjust

Scheduling is an iterative process where deviations are always expected since the first version of the schedule is more or less prediction. The first version of the schedule is based on the expectations and experiences from previous projects. Also assumption of normal amounts of crews and resources are used. In other words, the first schedule is the most efficient with the least direct cost. In many projects the schedule needs to be re-checked especially to shorten the duration of the project. Schedule adjusting starts with reviewing logical dependencies between tasks on the critical path, especially sorting out if some tasks can be done parallel instead of consecutively. It should also be checked if tasks with obvious time sparing potential can be found. Adjustments on the resources might be needed and levelling resources between tasks from non-critical activities to the tasks on the critical path is something to consider. In some cases, it is necessary to hire extra workers or plan overtime work if levelling resources between tasks is not enough or cannot be done. When adjusting the schedule, the extra costs are usually inevitable. It must be closely analyzed what are the benefits compared to the extra costs caused by the schedule changes. (Gould & Joyce 2009, p.220; Pelin 2011, p.132)

6.2.6. Monitor and control

The optimum schedule is the baseline or target schedule for the projects. As the project proceeds, changes will usually occur in every project and comparison between as-planned and as-built schedule is needed. In monitoring and controlling the schedule tools like bar charts, also known as Gantt charts, are used. Bar chart is a graphical representation of the project schedule shown in a bar line. Bar charts usually use x-axis to depict time and y-axis shows individual tasks. Project tasks run vertically down the left side of the chart and the task duration is identified along the x-axis. In modern programs progress and dependencies between tasks can be shown with arrows and color coding. (Mubarak 2010, p.14; Dykstra 2011, p.276)

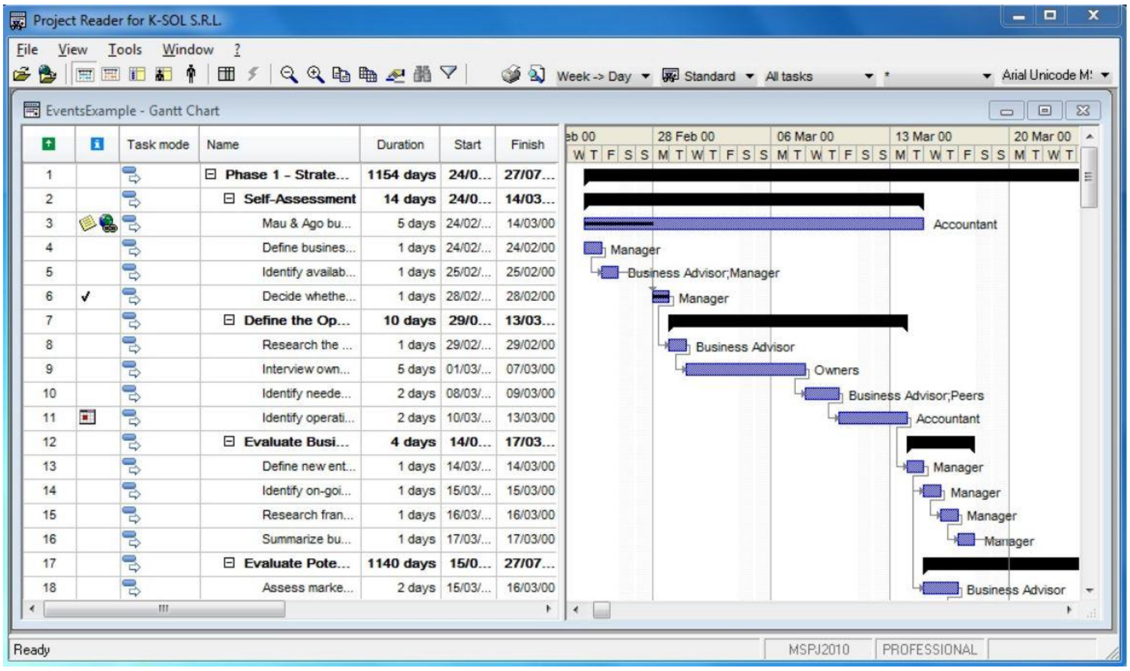

Figure 15. Bar chart. (Project reader)

Bar charts are widely used in construction projects because of their simplicity and ease of preparation and understanding. However, for projects with large numbers of activities bar charts may not be practical. The lines between tasks can get tangled and the chart might be difficult to read. To clarify the bar chart, events with significance can be created as milestones. Event is a point in time marking a start or an end of an activity. In contrast to an activity, milestones do not consume any resources, they are just points that will be passed. Milestones are usually certain points such as delivery, order, inspection, acceptance, start or finish of a certain activity. (Mubarak 2010, p.60)

7. Practical part

This chapter focuses on the practical part of the thesis. First, BHF process and principle are described and in the second sub-chapter the structure and the erection instructions are introduced. Third sub-chapter includes matters concerning BHF erection concept improvements and updated schedule.

7.1. BHF process description

The purpose of the bag house filter is to separate dust and other components from the flue gas stream by filtration through fabric filter bags. Filter bags are placed in separable compartments. Each BHF compartment is supplied with an inlet damper on the untreated flue gas side and an outlet damper on the cleaned gas side. During operation, any filter compartment can be shut down and isolated individually for maintenance work. If there is need to reduce possible acid gases (SO_2, HCl and HF), hydrated lime / sodium bicarbonate is injected into the flue gas duct upstream of the filter. Activated carbon can be injected to control the emissions of gaseous heavy metals, dioxins and furans.

Suction pressure generated by the I.D. fan draws the flue gases from the boiler back pass into the bag house filter. The flue gas flows through the vertically installed filter bags leaving fly ash, dust and additives on the outer surface of the bags. The cleaned gas then flows upwards inside the filter bags into the clean gas side of the filter and finally to the stack.

The layer of dust on the bags, the filter cake, consists of fly ash and solid reaction products. The chemical reactions that capture pollutants from the flue gas continue effectively in the filter cake as the flue gas passes through. The dust layer also improves mechanical separation of particles from the flue gas.

The filter bags are periodically cleaned by means of compressed air pulses. The air pulses are produced by dedicated pulse valves located on top of the header tanks in the penthouse. The cleaning air pulse is distributed by a pulse pipe to clean one row of filter bags per pulse (20 or 21 bags/row). The cleaning air pressure in the header tank is approximately 3 bar (g). A cleaning pulse is fired when the built-up pressure difference point over the filter is reached. If the set difference point limit is not reached within a certain time, the next bag row is cleaned based on a timer.

The cleaning pulse releases the filter cake, formed on the filter bags surface, and the cake drops into the ash hopper located at the bottom of each compartment. From the hopper the fly ash and reaction products can be discharged using ash screws / pneumatic transmitters. The ash hoppers are equipped with electric heating elements to maintain sufficient temperature in order to avoid corrosion.

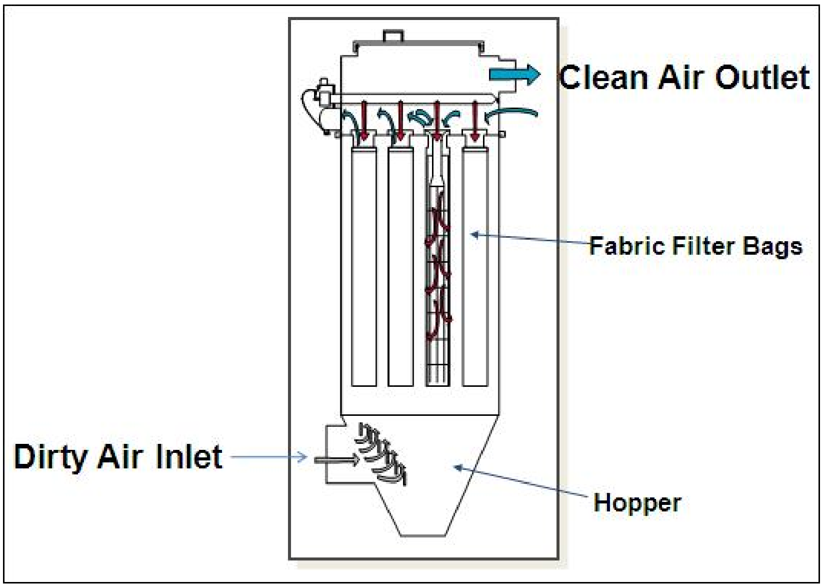

Figure 16. Flue gas circulation in BHF (Neundorfer)

7.2. BHF structure and erection instructions

Valmet has designed and delivered BHF over 10 years. Present BHF structure is executed in a few projects. In this chapter the structure of BHF and original erection instructions and sequence are explained. It must be kept in mind that although erection instructions are available, the actual erection sequence is always left for the contractor to decide. Erection instructions and sequences in this chapter are based on the ideas and knowledge what was available before the first BHF was built.

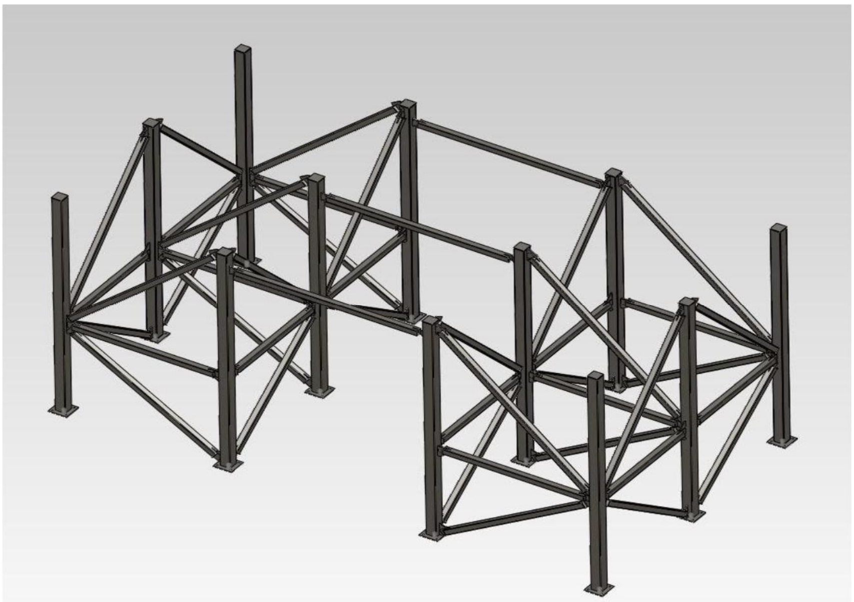

Figure 17. BHF steel structure

Erection starts with the supporting steel structure. Steel structure is erected on a concrete slab. Columns, beams and diagonals are fixed together by bolts and nuts and attached to the concrete slab according to the drawings. When installing the support structure, the level, cross-measure and the location of the columns must be checked. All the nuts are tightened using a torque key according to the instructions in the drawings.

Bottom hoppers are delivered to the construction site mainly in workshop manufactured panels and plates. Bottom part of the hopper, the smallest cone, is delivered in one piece. The panels and other bottom hopper parts are welded together on site according to the installation drawings. After the welding bottom hoppers will be lifted to the top of the steel structure onto the support slide bearings.

Figure 18. Bottom hoppers

Bottom hoppers can also be delivered to the site in one piece but transport costs are obviously much higher. In every case the most reasonable way for the delivery must be calculated and considered.

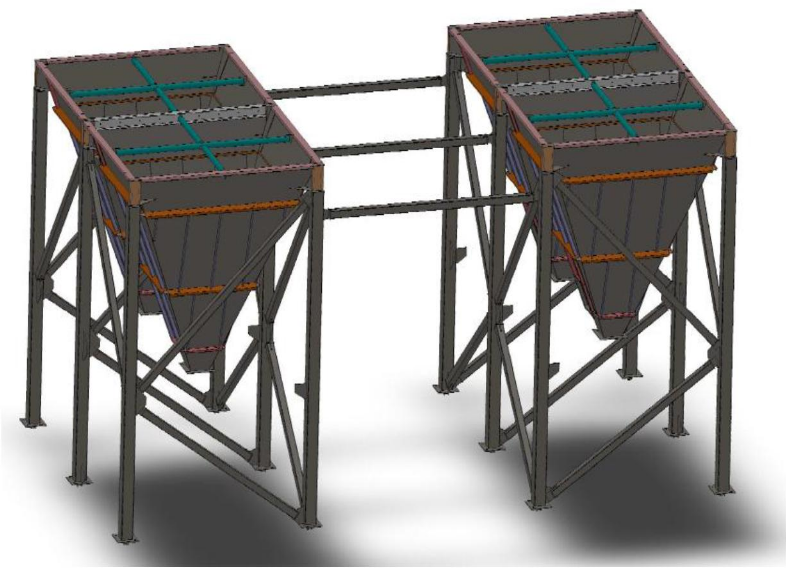

Figure 19. Bottom hoppers installed on the steel structure

Like the bottom hoppers, the casing or compartment modules are delivered to the site in workshop manufactured panels. Panels and other casing parts are welded together at the pre-assembly area according to the installation drawings. Compartment modules insulation can also be done in this phase. Unlike bottom hoppers, casings are not even considered to be transported to the site in one piece.

Nozzle house, which will be installed on the top of each compartment module, is delivered to the site in one piece. Compartment modules will be lifted onto the bottom hoppers. Once compartment modules are lifted, inlet dampers and inlet and outlet ducts are to be assembled to the compartment modules.

After that nozzle houses will be lifted on the top of the compartments and welded from inside. Scaffoldings need to be erected inside the compartments for welding.

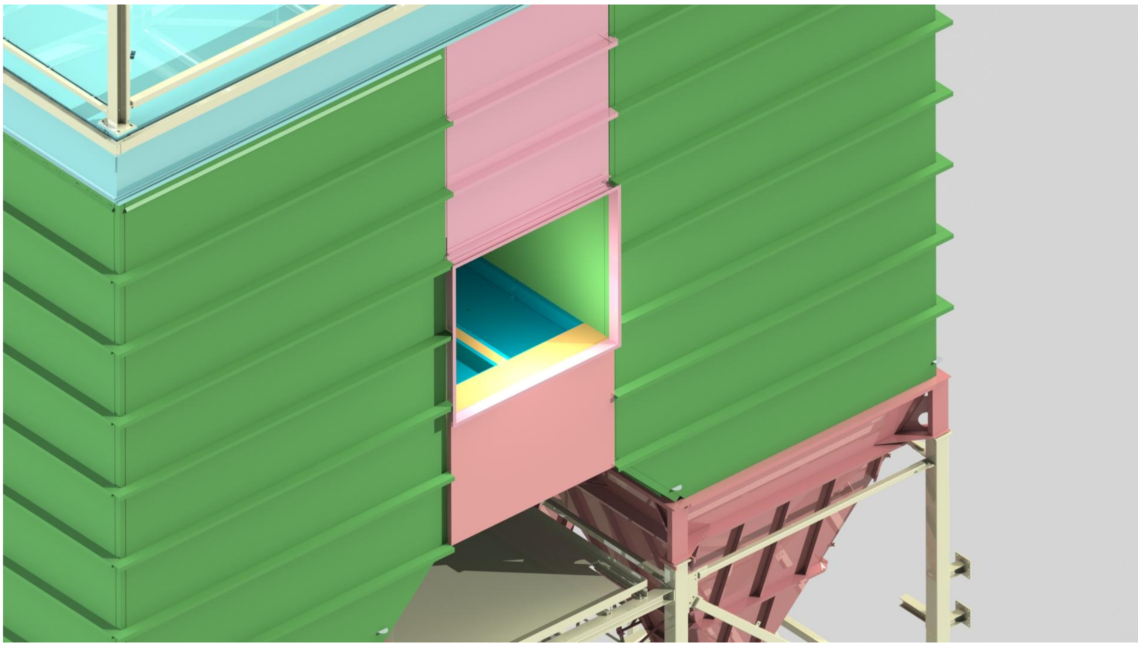

Figure 20. Inlet dampers and ducts assembled to the compartment modules

The last installed structure of the BHF is the penthouse. Before the penthouse, the header tanks are lifted on the top of the compartment modules. The penthouse is delivered as steel columns and beams and it is joined to the frame by bolts and bolted to the nozzle house. The penthouse is partly pre-fabricated on the ground before lifting.

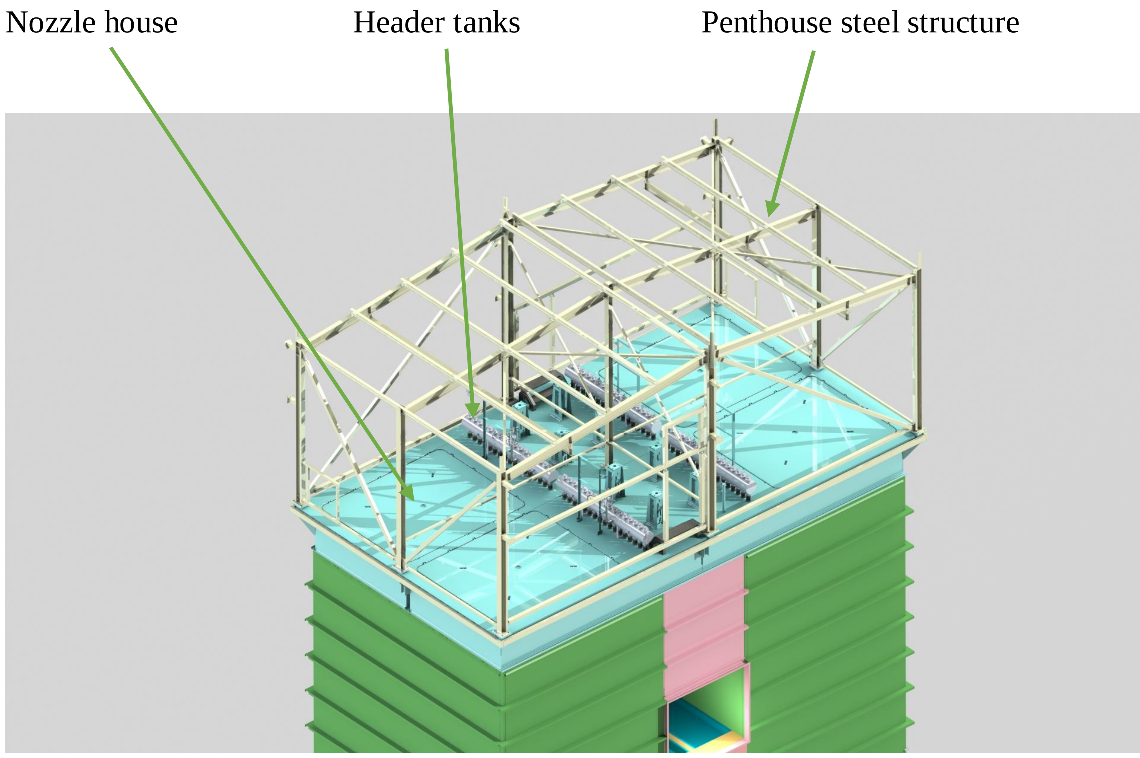

Figure 21. Penthouse steel structure, nozzle house and header tanks

After the penthouse is erected, it will be covered with outer roof. Installation of insulation and cladding are among the latest tasks to do in the mechanical erection of the BHF. Electric cables and some instruments have to be installed after insulation, and filter bags installation finalizes the mechanical erection.

Figure 22. Penthouse outer roof and side wall claddings

7.3. Lean BHF

7.3.1. The erection schedule for a 4-compartment BHF

The schedule shown in appendix 1 is quite ideal for a 4-compartment BHF using present erection methods and sequences. An improved schedule with updated erection ideas, bottom hoppers delivery to site fully assembled and inlet dampers, ducts and nozzle house installed before lifting, is shown in appendix 2.

Usually a BHF is erected at the same time with the boiler and the same subcontractor is used for both erection jobs. In these cases the boiler is always the primary object and the BHF is erected when it is suitable for boiler erection. This obviously delays BHF erection and the erection time is significantly longer. Other things that might slow down erection are lack of space on the construction site and in some cases the weather.

7.3.2. Modifications to improve BHF erection and installations

In the following sub-chapters ideas that help and speed up BHF erection and installations are discussed. Some of the following ideas are relatively small details but a few improvements can speed up BHF erection several days or even weeks. In addition, implementing new methods, more work can be done at the pre-fabrication area instead of the erection area. Most likely, all listed things below will not be implemented in reality but at least they are given a thought.

7.3.2.1. Matters concerning general working methods

Below are briefly listed general matters and ideas to be considered in the future which could be improved regarding working at construction site. Matters are not necessarily very big but their effect on the operations at pre-fabrication and erection area might be surprisingly significant.

Bigger pre-fabricated items. Less time for liftings needed if items could be lifted in bigger ensembles. Obviously, bigger cranes and other lifting devices will be needed and therefore the best option should be considered case by case.

Using special tools or lifting aid at site. Are there situations where some kind of special a tool or lifting aid would be useful?

More specific drawings. Based on the feedback from site supervisors, drawings could be even more specific. Added measurements and positioning would help checking the exact place for the objects. It would make installations easier and faster.

Small item logistics. Would it be reasonable to deliver small items in a bigger batch? Small items would be gathered to a temporary storage and delivered to the site in a bigger batch. Easier to control material flow at site when small items are not delivered one by one.

Some extra material delivered to the site on purpose. On every construction site repairs and modifications to ducting and piping are done. In these cases more material must be ordered and it takes some time to be delivered. If some basic material, for example metal sheets, would be available at site, needed modification could be done quicker.

Bigger tolerances. If possible, bigger tolerances for erection and installations should be considered in designing. In some cases too small tolerances make erection and installations very difficult.

Less welding and working on scaffoldings. It goes without saying. Welding and use of scaffoldings consume surprisingly much time and money at site. Every task should be planned in a way that excess welding and use of scaffoldings could be avoided.

7.3.2.2. Bottom hoppers delivery

The bottom hoppers can also be delivered to the site in one piece. This is a pretty easy way to save about two week pre-fabrication time at site. Transportation cost will be higher, so it must be calculated and considered in every project what is the best way for delivery. Also, welding costs in the workshop should be taken into account.

If the schedule is very tight, it might be reasonable, or even necessary, to deliver bottom hoppers fully fabricated to the site.

One option is to deliver bottom hoppers partly pre-fabricated to the site. Meaning that hoppers sidewalls would be in one piece and four side walls would be welded together at the pre-fabrication area. This procedure would save about one week welding work at the pre-fabrication area. Also transportation costs would be reasonable and special transportation arrangements are not needed.

7.3.2.3. Inlet dampers, inlet ducts and nozzle house installed on the ground level

Inlet dampers, inlet ducts and the nozzle house can be welded to the compartments on the ground level before lifting. If nozzle houses are installed before lifting, the impact on the erection schedule is significant. It would obviate difficult and time consuming scaffolding erection inside compartments. At the moment scaffoldings need to be erected inside compartments because nozzle houses are welded gastight from inside. It takes about three weeks to erect and dismantle scaffoldings and do the welding inside compartments. Obviously as much welding must be done but it would be done at the pre-fabrication area on the ground level, not at the erection area at the height of 15 meters.

An idea for the future concerning inlet dampers and ducts is that two dampers and ducts are manufactured as a pre-fabricated module in the workshop. That would save few days' work at the construction site. Module construction would allow dampers functionality and air tightness to be tested in the workshop before delivery. At the moment dampers are tested after BHF erection in the commissioning phase and it would be a benefit if tests had been done earlier. Testing in the workshop does not make BHF erection any easier but it would definitely make commissioning faster and safer.

Measures above would save about three week’s work at the erection area, and increase in work at the pre-fabrication area would be about 1-2 weeks. Hereby total savings for the project duration would be around 1-2 weeks.

7.3.2.4. Penthouse assembled and insulated on the ground level

In theory it would be possible to build the whole penthouse with insulation on the ground level. It would considerably reduce the work done on the scaffolding and insulation installation would be a lot easier. In practice it is a bit more difficult to execute.

On the ground level penthouse steel structure erection would need plenty of resources and space. Connecting columns and beams is hard because columns cannot be attached to the ground and therefore columns and the whole structure must be kept upwards some other way. It takes workers, all kind of devices and time to get the steel structure assembled. Additionally, the penthouse should be assembled at the erection area, transportation of the fully assembled penthouse is out of the question. Erection areas are usually pretty jammed and extra space is hard to find.

Lifting a fully assembled penthouse would also be challenging. Possibly temporary stiffeners should be welded to prevent the structure to collapse or twist. Secondly, penthouse is not equipped with lifting lugs and use of lifting chains or slings could damage insulation and cladding.

At the moment the scenery that the penthouse would be lifted fully assembled is not very probable. It needs definitely more planning before it can be implemented in practice.

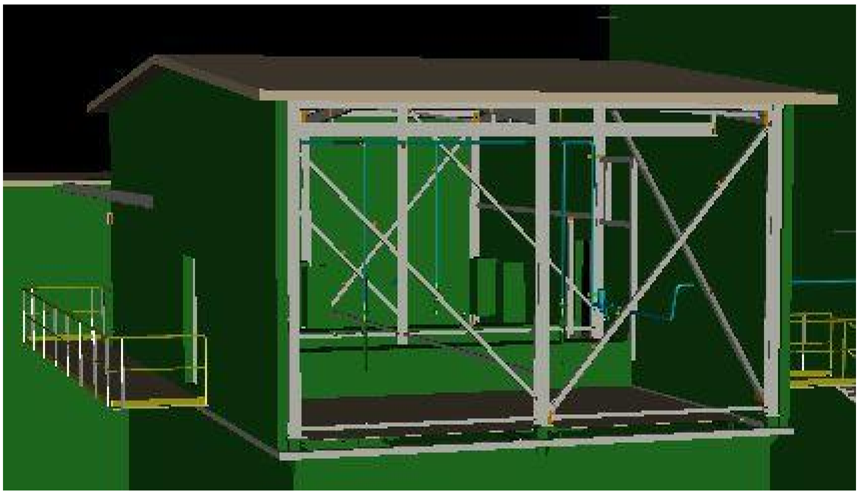

Figure 23. Penthouse without front wall insulation

7.3.2.5. Compartments insulated and cladding installed on the ground level

Compartments insulation and cladding can be done on the ground level at the pre-fabrication area. It would save significant amount of scaffolding work at 10-15 meters height. On the other hand, lifting fully assembled compartments would be challenging. Cladding is liable to damage and even a smallest hit would damage the surface. Another reckoned matter is the welding to be done above compartments. Although only some welding needs to be done, the cladding should be protected from sparks and spatters that the welding might cause. If the cladding is damaged, it must be changed and all the benefits achieved would be nullified.

This idea is not impossible to implement. However, it still needs further planning and some issues must be solved.

Figure 24. Two compartments partly insulated

8. Conclusion

In today's power plant project business competition is very tight and profit margins are very low. Competitive edge must be found on every possible way and that has set a real need to consider projects from every possible aspect. In delivery projects significant portion of the project's direct costs are committed at the construction site. BHF erections and installations are made comparatively fast at the site, and the average duration is 4-6 months. However, the goal is to reduce that time period as short as possible and the purpose is to keep site operation costs low. Well planned and scheduled erections, installations and material flow are essential for fluent site operations in order to keep costs in budget. Besides, customers want delivery projects to last as short as possible because power plants shut-downs cause income losses. Also, traffic and other activities at the construction site complicate their daily routines.

The goal of this thesis was to find improvement ideas concerning BHF erection and create an ideal schedule for erection. Part of the research was to find out if it is possible to move assembly work from the erection area to the pre-fabrication area. In some cases pre-assembly can be done at the subcontractor's workshop. In other words, the aim is to increase the degree of BHF pre-fabrication.

Pre-assembly area can be located a bit further from the erection area on a remote location. Usually work can start earlier at the pre-fabrication area because access to the area is available before than to the actual erection area. Obviously work accomplished at the pre-fabrication area reduce needed work at the erection area and it speeds up the erection schedule.

In this thesis all the possible knowledge and feedback from site supervisors, who have actually supervised BHF erection at site, is tried to be used. Some "good" improvement ideas, in theory, were rejected or at least reactions were a bit suspicious by the site supervisors. Reasons given for ideas dismissal were usually reasonable and well explained. Many erection ideas seem brilliant in theory but in practice many challenges may occur. That is why in erection planning experience gathered from construction sites is extremely valuable.

Even some of the development ideas presented in this thesis probably will not ever be implemented, a few viable improving ideas were found. It quickly became clear that huge break-through-ideas which would change the whole BHF erection concept cannot be found. In BHF erection many operations must be done in a certain way and order, and room for improvement in those operations is negligible.

Bottom hoppers delivery fully assembled to the site is the easiest way to save working time at site. However, transportation related matters should be sorted out in every project separately if bottom hoppers are considered to be delivered in one piece. I doubt that in every project this option is not economically reasonable but the time saving factor is obvious.

Inlet dampers, ducts and nozzle house installation before lifting seems a good idea and hopefully it will be implemented in the future. If this concept turns out to be working well, the positive impact on the schedule would be significant.

The research was quite successful as a whole. The objectives were accomplished to some extent. The results from the thesis showed that although BHF erection is a relatively simple project, there is some room for improvement in the erection concept. A fundamental issue regarding ideas discussed in this thesis is the fact that none of those ideas has not yet been implemented in practice. The challenge regarding erection scheduling is that all the bag house filters so far are erected together with a boiler. In these cases subcontractors always prioritize boiler and the effort for BHF erection is not the maximal.

BHF erection is surprisingly time consuming due to the large amount of welding, E&I and insulation installations. Experiences from previous projects have also shown that matters which vary between different projects must be taken into consideration. For example, penthouses do not need insulation if the weather is warm enough throughout the year. This leads to uncertainty in project scheduling and therefore the same BHF erection approach cannot be applied in every project. Every project is individual and must be considered case by case.

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